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Assessing employment in renewable energy technologies: A case study for wind power in Brazil

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ABSTRACT

Environmental concerns and the search for climate change mitigation have led to the deployment of renewable energy technologies (RET) in several countries. The adoption of incentive policies, especially those based on heavy subsides, has motivated the discussion of social and economic benefits brought about by these technologies, mainly on the impact on employment rates. In this context, several studies have been conducted to quantify job creation by RET, concluding that the latter are more labor intensive than traditional fossil fueled technologies. However, results for different assessments vary largely due to distinct methodological approaches, and are frequently highly aggregated. Thus, results are not comparable or applicable to other contexts. Previous studies have failed to quantify the effects of imports and exports of RET equipment in total employment, usually associating employment and installed capacity in the year studied. This study has aimed to address these issues, creating an index for employment quantification based on production, instead of installed, capacity. We have estimated both direct jobs in manufacture, construction, and operation and management, and indirect jobs both in the upstream supply chains of materials and inputs to manufacture of wind turbines and construction of wind farms. We have also performed an assessment of jobs created in wind energy projects which are expected to begin operation in Brazil until 2017. The resulting job potential in Brazil corresponds to13.5 persons-year equivalent for each MW installed between manufacture and first year of operation of a wind power plant, and 24.5 persons-year equivalent over the wind farm lifetime. Results show that major contribution from wind power for job creation are in the construction stage and, despite of the low amount of jobs created in operation and maintenance relative to new installed capacity, those stable jobs stand out as they persist over the entire wind farm's life time.

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1. Introduction

The search for climate change mitigation and the efforts for greenhouse gas (GHG) emissions reduction, since the Kyoto Protocol creation in 1997, have enhanced the search for alternative technologies that could meet economic needs, and simultaneously, generate lower environmental impacts. Among the popular measures, investments in renewable energy technologies (RET) became mainstream mitigation policies, and high efforts were put in the development and deployment of wind energy, especially in Europe. Along with mitigation of environmental impacts, innovation and job creation have also been cited as a driver for the development of RET in the past decade, justifying large investments, even during the financial crisis [1–3]. The slowdown of traditional markets after 2008, however, has led large companies to move part of their investments to emerging markets [4].

Since the early 2000s, several attempts to quantify employment from climate policies, and specifically from RET, have been made. Even though previous studies differ in methods and assumptions, they usually use a common metric to assess the potential employment in future scenarios: jobs (or jobs-year) created per installed capacity. However, the most used current methodology is not transparent enough to be compared and applied to different contexts than the one considered in each study, since the functional unit is usually based on installed capacity, rather than production capacity.

Accordingly, this research was conducted with the primary aim of developing an approach that would allow the evaluation of job creation in developing markets, which experience continuous and rapid industry growth, shifting from import-oriented to domestic production. An ideal method would permit cross-country comparison of job creation in RET and internalization of effects of equipment and services imports and exports. Imports and exports of equipment have employment effects not only in the RET industry, but also in the rest of the economy from which goods and services derive.

We have combined an estimation of potential direct jobs and material requirement in the production of equipment and construction and operation of wind power plants, with a hybrid economic input–output life cycle assessment to evaluate indirect employment in the upstream supply chain of material inputs. We have applied this method to investigate the contribution of wind power to job creation in Brazil.

After being the pioneer in the installation of wind farms in Latin America, and later in the adoption of incentive policies, Brazil has had tremendous growth in the volume of contracted wind projects since 2009, and became the most attractive Latin American market. In 2011, the Brazilian wind market was considered the 9th best global market for investment [5]. Wind power still offers a low contribution to power generation in Brazil. However, in recent years, the wind energy sector has witnessed a rapid increase in the number of purchased projects, and installed capacity is expected to increase by fivefold in only five years. The wind turbine industry is also experiencing fast growth, and is expected to significantly increase production capacity over the next few years. In this context, it is essential to assess the impact that the rapid growth of the wind power industry might bring about to the Brazilian economy. One important aspect to be considered is the potential demand for employment throughout the life cycle of a wind power project and its supply chains, in order to provide a basis to support the creation and management of energy and industrial policies for the wind power sector.

This article is divided in 5 sections. The following one reviews previous studies on employment assessment in renewable energy technologies, while the third section presents the methods used in this study. It follows the results of the methodology application and an employment assessment to the next five years in Brazil, closing with a discussion on main results and research highlights.

2. Employment assessment in renewable energy technologies: A review of previous studies

Despite the nearly consensus that job creation is more intensive in renewable energy than in fossil fueled technologies, as shown in studies summarized in UNEP et al. [6] and in Rutovitz and Atherton [7], previous studies results differ greatly. The analysis of these assessments suggests that there is no standard methodology to carry out the assessments [8,9], and results are shown in highly aggregated level, which does not allow their comparison or use in other contexts.

Usually, methods used to determine the potential of jobs created by RET rely on input–output methods, analytical methods or a combination of both [9–11]. The combination of an analytical method, which is a bottom-up and process based approach, with input–output models, which are a top-down and macroeconomic based approach, leads to a hybrid method, similarly to a hybrid life cycle assessment (LCA) approach,[1] that can cover a higher spectrum of employment categories. The usual approach to assessing jobs created by energy generation technologies (as seen, for example, in Refs. [13,14] and discussed in Ref. [15]), often used for constructing scenarios of future employment, is creating ratios of jobs created per installed capacity. The commonly used method is represented by Eq. (1)

$$\text{Index of direct jobs} = \sum \text{employees in RET} / \text{Installed capacity} \qquad (1)$$

The employment index, expressed in "jobs/MW" or "jobs-year/MW", would be the ratio between total employees in RET-related activities (or for each activity) in a year and the incremental RET installed capacity in the same year, in MW. For example, if the studied year had 10,000 jobs created in wind power related activities, and 500 MW of wind energy was installed in the country in the same year, the employment rate would be of 20 jobs-year/MW.

Dalton and Lewis [15] argue that this is not an effective measure for assessing the effects of renewable energy on employment, since it does not compute the employment benefits for the economy and the population. Countries with export-oriented RET industries have a high rate of employment, which does not reflect job generation by installed capacity. One example cited is the case in Denmark in 2007, which was the second country with the highest number of jobs created in wind power industry that year due to the export-oriented industry, but exceptionally installed only 3 MW, generating an unusual rate of 7833 jobs/MW. They

[1] Mathematically, this method is similar to hybrid LCAs as illustrated in Ref. [12].

showed that changes in renewable energy policies can greatly affect the installed capacity in a given year, but failed to offer a feasible solution to calculate job creation without relying on the fluctuating capacity installed each year.

That fact could also be responsible for the high share of jobs in manufacture in Europe, with more than 80% of direct and indirect jobs in 2008. In the study, 75% of the jobs were concentrated in Denmark, Spain and Germany, main wind turbine components exporters [16]. The importance of exports is also recognized as important in a study by Lehr et al. [17], in which long term employment gains in RET in Germany, compared to traditional energy technologies, depend on the maintenance of a strong export oriented industry.

The contribution of RET to direct and indirect jobs in Portugal was evaluated in a recent study which applied a sensitivity analysis to determine the effects of domestically produced goods versus imported goods in the supply chain of technologies. Results show that the socio economic effects of RET development are maximized when a considerable share of manufacturing takes place in the country [10]. Another study evaluated the potential of job creation by RET in the Middle East based on employment factors from a literature review. The estimates have considered average values and the minimum and maximum employment factors for wind and solar [18]. The study also compares a scenario in which most manufacturing activity takes place in the Middle East versus another in which part of the manufacturing activities takes place abroad. Although capturing the effects of trade balance is fundamental in assessing the local employment generation potential [8], there is still little consideration about the importance of imports and exports of equipment on employment rates.

A comparison provided by Blanco and Rodrigues [13] based on previous studies, which have quantified job generation by wind energy, shows that employment rates per MW installed may vary significantly between studies, due to the assumptions, methodology, and boundaries adopted in the studies. Fig. 1 summarizes the wide variation between the indexes of employment per MW installed found in the literature and mean value (diamonds) for each energy technology, and Table 1 shows the definition of direct and indirect jobs in several studies.

The wide variation in job creation rates arises mainly because of two reasons. The first is spatial and temporal differences, which might affect the technology nationalization index (amount of components and equipment that are domestically manufactured and services domestically provided out of the total used, calculated either on mass or monetary basis), the installed capacity in the year, components imports and exports, the level of technological development in the country (the number of workers related to equipment manufacturing and installation tends to decrease due to increasing returns to scale, automation, and increasing yields [17,19]), and also depends on the country's and industry's labor intensity, among others. Also, results are often shown in aggregated values, not accounting for each stage of manufacturing or the effects of imports and exports in final indexes. This transparency is crucial for potential employment assessments in developing markets, in order to subsidize industrial policy. The second factor is the methodological difference, which includes not only the tool used to quantify, but also the scope, assumptions, and data sources. Thus, each case must be examined separately, and the use of indexes produced in other contexts to estimate job creation by a RET in another time or place should be avoided [7,4].

Another difference between the assumptions of the studies is the definition of direct and indirect jobs. Overall, manufacturing of key components, power plant construction and operation and maintenance (O&M) are considered direct jobs. However, other studies include planning and project management, research and development, energy companies, utilities, banks, and other services. Nevertheless, the definition of indirect jobs is even vaguer. While some authors estimate, through the use of input–output analysis (IOA), the indirect effects of materials and services consumed on the upstream supply chain, other studies consider consultancies and several minor components not directly related to the sector. There are also studies which include induced jobs (those created due to expenditure of salaries from new employment in the domestic economy) in the final quantification. With few exceptions (e.g. [20–22], studies do not usually take into account job losses in other energy industries or due to high investments costs of RET. The difference of the assumptions made in different studies quantifying employment in power generation technologies is summarized on Table 1.

The treatment of the differences between temporary and permanent jobs is also an issue that is often not addressed in the studies. Direct jobs can be broadly divided into two categories. The first refers to employment in the early stages of RET, from

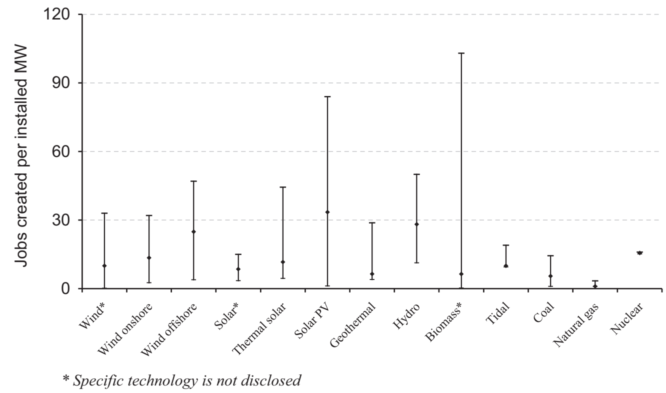

Fig. 1. Review of literature indexes of jobs created per installed MW of capacity for different energy technologies [2–5,7–10].

Table 1
Summary of assumptions from previous studies.

Source	Direct jobs	Indirect jobs	Induced jobs
Capros et al. [23]	M+C+O&M[a]	IOA[e]	Included
Singh and Fehrs [24]	M+C+O&M[a]		
EWEA [16]	M+C+O&M[a]+OS[b]	ONRS[d]	
Lehr et al. [17]	M+O&M[a]	IOA[e]	Included
Moreno and López [14]	M+C+O&M[a]		
Pollin et al. [25]	IM+C+O&M[a]	IOA[e]	Included
Thornley et al. [26]	O&M[a]	C[a]+SC[f]	Included
Blanco and Rodrigues [13]	M+C+O&M[a]+OS[b]	ONRS[d]	
Rutovitz and Atherton [7]	M+C+O&M[a]		
de Moraes et al. [27]	NA[g]	NA[g]	
Wei et al. [28]	M+C+O&M[a]+PM[c]	IOA[e]	Included
Dalton and Lewis [15]	M+C+O&M[a]		
Tourkolias and Mirasgedis [29]	M+C+O&M[a]	IOA[e]	Included
Mukhopadhyay and Thomassin [30]		IOA[e]	Included
Neuwahl et al. [31]		IOA[e]	
Wang et al. [11]	C+O&M[a]	IOA[e]	
Llera et al. [8]	M+C+O&M[a]	IOA[e]	
Oliveira et al. [10]		IOA[e]	
van der Zwaan et al. [18]	M+C+O&M[a]		

[a] M+C+O&M: Manufacturing+Construction+O&M.
[b] OS: Other services, such as R&D, energy trading and distribution, banking, planning and management.
[c] PM: Project planning and management.
[d] ONRS: Other non-directly related services such as secondary component manufacturing and consulting.
[e] IOA: Jobs in the upstream supply chain through input–output analysis.
[f] SC: Supply chain.
[g] NA: Not available.

equipment manufacturing until the power plant construction. Such jobs are temporary, since they are demanded only until the power plant is ready to operate, and are usually treated as “job-years”. Although some authors treat these jobs as permanent (see, for example, Sastresa et al. [19]), they will exist only when there is a demand for equipment, i.e. when there will be new capacity. If a country ceases the construction of new projects, jobs in manufacturing will have to shift towards exports or migrate to other sector. The second category refers to jobs in O&M of the power plant, and has a non-temporary feature, since it will last over the lifetime of the project. The latter is usually called “jobs”. Therefore, a special treatment is required for the integration of both categories.

Moreover, an explicit accounting of jobs in different life cycle phases of the RET is fundamental because some specific phases might stand out in terms of job creation potential. A previous study concluded that when future wind penetration scenarios are considered, O&M is the life cycle stage responsible for most of the jobs created [18].

One possibility is normalizing all temporary jobs throughout the life cycle of the project, dividing the number of job-years by the plant's lifetime. However, despite being a simple and comparable metric, it does not reflect the real impact generated by technologies that have high rates of growth and potential for generating large amounts of employment in a year, as it is the case of RET [28].

It is also noted that most studies estimating jobs in RET are concentrated in North America or Europe [9], and only few studies are applied to emerging markets, where technology and local production are still at the development level.

In this study we propose a different approach to index construction. This approach in this study differs from the one usually found in the literature in three aspects:

(1) The new employment index does not reflect the jobs occupied in the country in the year studied, but the labor intensity of the different life cycle phases of RET, i.e. the employment generation potential according to the output capacity, in MW, for each activity;
(2) The indexes are separated not only by activities (manufacturing, construction and operation) but also by components, which can be easily updated and used in sensitivity analyzes related to the domestic content of products and materials;
(3) The rate of employment is measured in job-years, and permanent jobs generated during the lifetime of the project will be accounted for in each year of operation.

The index is described in Section 3, where the detailed methodology is presented.

3. Methods

In contrast to the usual approach to job quantification in RET, focused on installed capacity, we concentrated on the production capacity of RET technologies. Employment quantification followed three main steps:

(a) *Life cycle perspective*: identification of main activities and inputs for wind energy production through bibliographical review and experts opinions.
(b) *Data collection from reviews and interviews*: quantification of main inputs for manufacture of wind turbines and construction of wind farms, and quantification of direct employment in manufacture, construction and operation and maintenance (O&M). Personal interviews were conducted to wind power plants managers, O&M technicians, representatives of six wind turbine components manufacturers (blades, concrete and steel towers and nacelles), project managers and environmental agencies. All data was collected between the second semester of 2011 and the first semester of 2012. Manufacture capacity refer to 2011, while construction and O&M stages refer to wind farms in operation in 2011 and 2012. Review of onshore wind turbines life cycle assessments were used to estimate inputs into manufacture [32–34].
(c) *Construction of employment indexes*: Employment indexes were calculated for direct and indirect employment for manufacture of blades, nacelles and towers, construction, and O&M of wind power plants. Employment was normalized for one year (person-year equivalents, p-y_{eq}), and correspond to jobs occupied in the year of operation. Indexes construction is described below.

Detailed information on activities and inputs considered, and interviews and data collection, can be found in the Supporting information.

3.1. Direct employment

While direct employment is usually normalized by installed capacity in the year assessed, this study has aimed to quantify potential employment in each activity according to actual employment/production ratio. In this manner, effects from imports and exports can be accounted for scenario development and policy making. Data collected from review and interviews can be found in the Supporting information, and are summarized in Table 2.

For direct employment in manufacture, employment index ($In_{D,man}$) was calculated according to maximum output capacity for each component manufacture. That approach allows the identification of constraints to domestic production in scenario constructions. We did not build new scenarios, but rather assessed employment to be created in wind power projects purchased until September 2013. Indexes represent the potential jobs created for each 1 MW purchased from wind power turbines industry, as reflected in Eq. (2). Indexes were created separately for each main component: nacelle, tower (steel and concrete towers), and rotor.

$$In_{D,man} = E_{100\%}/C_{100\%} \tag{2}$$

Direct employment index for construction ($In_{D,cons}$) was calculated for each wind farm with available data (see Supporting information for details) as the ratio between persons occupied in the construction and the power capacity of the wind power plant, normalized for one year (persons-year equivalents), as in Eq. (3).

$$In_{D,cons} = (E_{cons}/C_{wind})(T_{cons}/12) \tag{3}$$

For O&M, indexes for direct employment ($In_{D,O\&M}$) were calculated as a relation of employees for wind power capacity, as in Eq. (4). O&M employees were considered those directly working in all activities inside and exclusively for the functioning for the wind power plant—operation and maintenance technicians, cleaners, security, environmental technicians and managers, and power plant managers. Off-site (*ex situ*, expert) maintenance employees were also included, and calculated as a ratio of employees available for *ex situ* maintenance in the region and the wind power capacity covered by those employees. We did not consider substitution of spare parts of wind turbines for indirect employment. Differently from the rest of the indexes, O&M index is not related to new installed capacity, but to existing capacity in the

Table 2
Data and nomenclature for information collected for index construction.

Activity	Nomenclature	Description
Manufacture (Man)	R_{man}	Raw material inputs, in physical units, for manufacture of each component
	$C_{100\%}$	Maximum annual production capacity, in MW, for each component
	$E_{100\%}$	Jobs occupied for maximum annual production capacity, in persons
Construction (Cons)	R_{cons}	Raw materials inputs, in physical units, for construction of each wind farm
	C_{wind}	Wind power plant capacity, in MW
	T_{cons}	Time for construction for each wind power plant, in months
	E_{cons}	Jobs occupied in construction of each wind farm, in persons
Operation and maintenance (O&M)	C_{wind}	Wind power plant capacity, in MW
	$E_{in,O\&M}$	Jobs occupied in O&M in each wind farm, in persons
	$C_{r,O\&M}$	Wind power capacity in region covered by *ex situ* maintenance company
	$E_{ex,O\&M}$	Jobs occupied by maintenance technicians in *ex situ* maintenance company

year.

$$In_{D,O\&M} = (E_{in,O\&M}/C_{wind}) + (E_{ex,O\&M}/C_{R,O\&M}) \quad (4)$$

For the purpose of simplification, and due to unavailability of time and data, we did not consider services to wind power projects—research and development, consultancy, financing, environmental licensing, wind resource measurement and modelling, energy commercialization, and others. Services and material suppliers, from designing of the project, project management, financial services, construction and operation, involve dozens or even hundreds of suppliers, and boundaries and job estimation to these services are many times not very well defined, since those services are not exclusive for wind power projects.

3.2. Indirect employment

Indirect employment was defined as jobs created throughout the economy due to the consumption of inputs from the economy. Those jobs were calculated through a hybrid input–output model, where we used the technology (A) matrix – or the recipe – for the production of the inputs. We used the A matrix from the last publicly available input–output model for the Brazilian economy, from 2005 [35], combined with labor data for the same year [36]. It was assumed that the proportion for jobs occupied (e) for the production of a fixed monetary value and the interrelation of different sectors in the economy remained constant—due to the lack of newer data. A detailed description of calculation and explanation on input–output multipliers is available in the Supporting information.

Indirect employment (E_I; Eq. (5)) was calculated for each input into manufacture and construction (e.g. cement and steel) through the multiplication of employment multipliers (M) from the input–output model, the raw material input (R) in physical units, and a price matrix for 2005 (p; in millions of Brazilian Reais per physical unit). Indirect jobs were calculated for both manufacture ($In_{I,man}$; Eq. (6)) and construction ($In_{I,cons}$; Eq. (7)).

$$E_I = M \times (R \otimes p) = [e(I - A)^{-1}] \times (R \otimes p) \quad (5)$$

$$In_{I,man} = E_{I,man} / C_{100\%} \quad (6)$$

$$In_{I,cons} = E_{I,cons} / C_{wind} \quad (7)$$

In the equations above, I is an identity matrix (more information on how to calculate the multipliers can be found in the Supporting information). All indexes are reported separately and aggregated; the former, to allow comparison and scenarios accounting for imports and exports, and also to guide policy makers in industrial policy priorities, and the latter to facilitate application and communication.

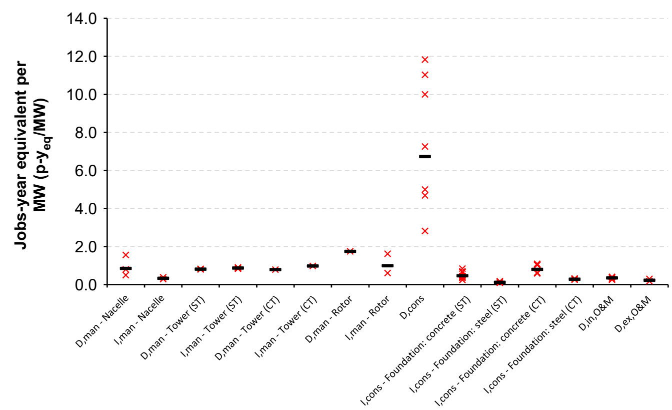

Fig. 2. Direct and indirect employment indexes for all activities considered in the study, in all samples (×) and geometric means (–).

Total employment index for each activity is the sum of aggregated direct and indirect indexes. All indexes are expressed in persons-year equivalents (p-y_{eq}), a comparable unit, although they have different meanings for each activity. While in manufacture and construction they reflect temporary workers—or on-demand workers, whose work happen in the spam of one to two years and depend on each project, O&M employees are considered permanent workers, and each project reflects an increase in job positions in the region. Therefore, for the whole lifetime of the power plant, each worker employed in O&M will represent n jobs-year, being n the wind power plant's lifetime, in years.

When more than one data was available for jobs occupied in a certain activity, indexes were calculated for each of the data points available and final indexes were calculated as the geometric mean value of those. For the sake of simplification, jobs created in all activities were assumed to occur in the first year of operation.

For the application, indexes for manufacture and construction should be multiplied by new capacity, while index for O&M should be multiplied to cumulative existing plus new capacity, in MW.

4. Results

4.1. Employment index

Data collected are detailed in Supporting information and illustrated in Fig. 2 and Table 3. Direct jobs created in construction have showed the greatest variability, and also corresponded to the main share of job creation in wind power—over 55% of direct jobs, and 40% of total jobs. Total job-year indexes sum 15.3 p-y_{eq} for steel towers (ST) and 15.8 p-y_{eq} for concrete towers (CT). Direct jobs have corresponded to 75% of total jobs for steel towers wind turbines, and 80% for concrete towers. The only activity where

Table 3
Direct, indirect and total indexes of persons-year equivalent per MW for activities and components in wind power industry.

	Employment index (p-y_{eq}/MW)		
	Direct	Indirect	Total
Manufacture:			
Nacelle	0.85	0.34	***1.19***
Rotor	1.75	0.99	***2.74***
Tower (Steel)	0.81	0.87	***1.69***
Tower (Concrete)	0.79	0.98	***1.77***
Construction			
Steel tower	6.73	0.59	***7.32***
Concrete tower	6.73	1.09	***7.82***
O&M	0.59		***0.59***
Total (steel tower)	**10.74**	**2.79**	***13.53***
Total (concrete tower)	**10.71**	**3.40**	***14.11***

indirect jobs have scored higher than direct jobs was in tower manufacture, for both steel and concrete.

4.2. Comparison of methods

The index usually adopted in most studies – total employment per installed capacity – and the one used in this assessment can be easily compared. Since data for total jobs occupied in the wind power sector in 2011 was not available, we illustrate by comparing jobs created solely in the blade manufacturing sector.

According to information published in business newspapers in Brazil [37,38], in 2008, the largest blade producer in Brazil – and one of the largest in the world – employed around 4500 people. In the same year, new wind power installations corresponded to 77.8 MW, leading to a surprisingly high index of over 57 persons-year equivalent employed in blade manufacturing per MW installed in the country. In 2012, the same company employed around 6000 persons, while 1077 MW were installed – resulting in an index of 5.1 persons-year equivalent employed in blade manufacture per MW installed. This last figure can even be considered underestimated: while in 2008 this company – Tecsis – corresponded to most of the blade manufacture in the country, in 2012 there were other 3 companies manufacturing blades in the country.

In 2012, Tecsis manufactured around 5.5 thousand blades—or around 3600 MW. Using the method in this assessment, the estimated index is of 1.5 persons-year equivalent per MW of blades manufactured. This last index is similar to the one calculated in this study, of 1.65.

The difference between both indexes can be explained by answering a simple question: where and when are the blades manufactured in the country being installed? Both in 2008 and in 2012, the majority of the equipment produced by Tecsis were exported. Also, manufacture usually occurs in the previous year to the operation of the wind farm. In growing markets, where installed capacity can double from one year to the next, comparing manufacture and operation both taking place in a same year can lead to an overestimated index for manufacturing activities. The difference in indexes calculated from MW installed in both years by the same company show that employment indexes cannot treat domestic and international markets on the same basis. It is, thus, preferable to build an index based on equipment manufactured, which permits to evaluate impact of imports and exports, than based on installed capacity in a determined year.

4.3. Employment assessment in wind power in Brazil

Employment creation was modeled for wind power projects purchased until September 2013, which are estimated to operate until 2017. Jobs created each year correspond to an annual picture of the situation, and are not related to permanent new jobs generated, but all the jobs related to the wind power supply chain in a given year. For modeling purposes, we have used the most common tower technology deployed in Brazil, which are steel towers. We have also considered 100% of major components and inputs produced in the domestic industry. By the end of the period, in 2013, around 170 thousand persons-year equivalent will be occupied: 82 thousand in construction, 63 thousand in manufacturing, and 26 thousand in O&M (Fig. 3).

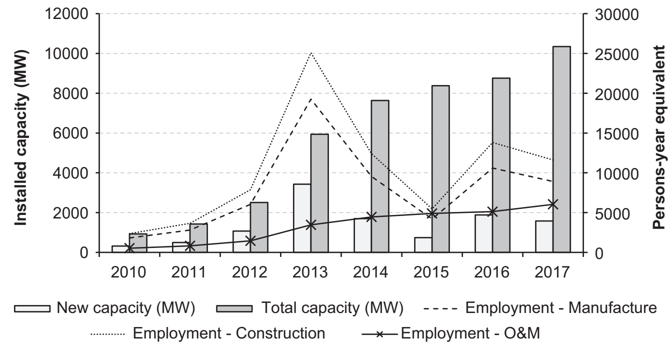

Fig. 3. Wind power capacity, in MW (bars, left axis) and estimated employment, in persons-year equivalents (lines, right axis) for expected wind power capacity between 2010 and 2017.

Imports could reduce up to 40% of all potential jobs, considering the loss in all manufacturing jobs. Construction and O&M stages create local jobs, which would not be affected by imports or exports.

5. Discussion

Indexes for job creation per MW installed are the most popular measure for employment quantification in energy scenarios. One could argue that an effective measure could be jobs created per unit of energy produced – for instance, jobs-year per GWh – to allow a comparison among different technologies in broad energy planning. However, a first step to accomplish this is to measure employment from physical capacity, i.e. installed capacity.

The widespread methodology for employment evaluation is accounting for total persons employed in the sector and installed capacity in a reference year. Nevertheless, this approach leads to an inaccurate result, as discussed in Section 2. In this study we have presented a method capable of internalizing the imports and exports in the employment index, as well as the time lag between production and installation of equipment. This method can bring more precision to employment assessment in different wind energy deployment scenarios because it shows the exact number of jobs occupied for every year.

Although in terms of jobs in manufacturing the distinction between imported versus domestic made goods is important, in the present assessment we have estimated that construction jobs, which are intrinsically domestic, were responsible for most of the jobs associated with wind development. Therefore, for the Brazilian case and the case of imports only, losses with imports of equipment could affect up to 41.5% of total job creation.

In our assessment we have highlighted that when the effects of international trading are ignored the number of jobs associated with RET deployment might be inflated. In addition, the method adopted in the studies to compare and aggregate perennial jobs and temporary jobs might inflate jobs potential of RET as well. In this vein we believe that it is important to evaluate the jobs potential for every life cycle stage of the project. Indeed the

treatment of temporal differences is key in the assessments. In addition to differences in the duration of the employment period, the time lags between fabrication, installation, beginning of operation, and decommissioning must be explicitly treated in the analysis. If the purpose of the assessment is the evaluation of a RET deployment scenario, with the commissioning of new projects every year, it is possible to simply sum up all types of jobs for every year and report the annual number of jobs. However, if the goal is to evaluate the potential of job creation for a project or a region, in a non-temporal manner, jobs in O&M should be either separated from temporary jobs in manufacture and construction and treated as permanent jobs instead of jobs-year equivalent, or summed for all years and added to temporary jobs. To illustrate these two accountings, taking the rounded index of 13 p-y_{eq} for manufacturing and construction and 0.6 p-y_{eq} for O&M, a hypothetical 10 MW wind farm would create 130 p-y_{eq} and 6 permanent jobs in O&M in the first approach, while for the second one that same wind farm would have the potential to create 130 p-y_{eq} in manufacturing and construction plus 120 p-y_{eq} in O&M during its 20 years lifetime. Although both are valid ways to communicate the results, one should be careful to make clear that the latter is spread in a 20 year period.

5.1. Uncertainties

To calculate the average indexes we analysed different data obtained from interviews and, in the case of indirect employment, literature review. However, some uncertainties can be named, such as few data for some equipment manufacturing, high variation in indexes for each project analysed, the choice of the type of average, and uncertainties from the methodology choice.

Indexes for direct jobs in the construction stage have a high variation and high labor intensity. This can be due to: (a) high labor intensity in manufacture and especially construction activities in Brazil compared to more developed markets; (b) development stage of the industry in the country, with major efficiency gains to be expected in the next years; (c) uncertain data obtained from companies—especially in construction stages, where peak of employees does not last for the entire construction period, but no data was available on a monthly basis.

To make sure uncertainties due to averaging of values – especially for direct jobs in construction – we decided to calculate three average values for direct jobs, besides the geometric mean used: non-weighted average, weighted average, and median. Difference between the highest (non-weighted average) and lowest (geometric mean) values for construction was of 0.78. The median of the values obtained was 7.12, with an error of 0.39.

Indexes for indirect jobs have uncertainties related to input–output models, especially in aggregation issues. Due to the relative high aggregation, important materials – for example, different types of steel, such as cheaper steel bars for foundations, and high quality and more expensive steel plates for tower manufacture – are aggregated into the same sector and, therefore, have the same multipliers and the same price matrix. For all these products, average technology and average employment coefficients are used, what could result in uncertainties to the model. Moreover, the IOA is based on a 2005 technical coefficients matrix.

6. Conclusion

This study aimed to discuss methods for employment assessment in renewable energy technologies and propose changes to internalize the effect of international trade of equipment into employment assessment. We applied this method to the wind power industry in Brazil, estimating direct and indirect jobs indexes for manufacture of wind turbines, construction and operation and management, normalized for each MW installed. Our results suggest that the construction stage has the higher potential to generate jobs, and differ from previous studies which identified manufacturing stages as the most labor intensive. However, previous studies were mostly conducted in equipment exporter countries, and without excluding production for exports from their index. We have evaluated the number of jobs occupied in the country due to wind power development in Brazil from 2010 to 2017. Considering wind power projects already installed or acquired until September 2013, jobs occupied in the period are estimated to be of 170 thousand persons-year equivalent.

There is a myriad of methods to quantify jobs in RET, and we believe that a scenario-based method in which it is possible to get a clear picture of the number of jobs related to each activity (manufacturing, construction, installation, and O&M) for a specific year is an valuable approach. Accounting for production capacity also allows for the application of the index to scenarios of imports and exports of equipment. In that manner, scenarios can contemplate diverse policy options in developing wind power markets.

Although the index reflects Brazilian wind power industry employment and economic conditions in 2011, and should be applied with caution, the method described in the paper can be easily revised with updated information and applied to other situations. Moreover, considering impacts on the upstream supply chain is also important to guide industrial policy for RET.

To contemplate a sustainable energy policy, economic, environmental and social aspects should be thoroughly assessed. Job creation in renewable energy technologies is an aspect that covers those three premises: a low-carbon economy by the deployment of renewable energy technologies, and social and economic development in both local and regional scales through income generation and capacity building, especially in isolated rural areas.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.rser.2013.11.046.

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